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Research paper

Account of Temperature Change at Calibration of Air Flow Sensor

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Abstract

The article describes of temperature change consideration during the calibration of air flow sensor for a car engine. The sensor uses a blade made of elastic material with strain gauges applied to the front and the back surfaces, the deformation of which is measured and recalculated into a mass flow of air. They suggested the system of equations whose solution makes it possible to determine the mass flow rate and air temperature according to the known signal values at the measuring bridge output and the measuring circuit resistance. The coefficients of equation system are determined during calibration and then are recorded into the memory of the microcontroller sensor.

***Key words**: mass air flow sensor, temperature, least squares method, measuring circuit, calibration, strain gauge transducer*.

1. Introduction

In modern control systems using electronic means of signal processing, the measured values at the system input are converted into equivalent electrical parameters (voltage, current, frequency) by the means of sensors. A sensor is a device that generates an equivalent signal at the output under the influence of the measured physical quantity. This signal is the function of the measured quantity: s = F(m), where s is the equivalent value at the sensor output, m is the value of the measured physical quantity at the sensor input (Kokoszyński, D. et al., 2002).

The issues of sensor and measuring path calibration were considered in a number of works. In the work (Vilop L.E., 2012; Książkiewicz, J. M., 2003) the autocalibration of electric value transformation channel was considered on a two-element simulator of an output electric value of the gauge in the measuring system with non-linear sensors. It was shown that when you use sensors with a nonlinear conversion function in a measuring system with an autocalibration according to the simulator of a sensor output electrical value with two measurement values, the calibration with the use of an external multivalued measure of the sensor output electric value at the range points is the mandatory procedure (Mazanowski, A. et al., 2001).

In work (Gritsenko A.V. et al., 2013) they provided the results of intellectual gauge model study using the method of self-diagnostics which is based on the use of transformation function nonlinear properties of a controlled device, and is realized by the analysis of an output signal noise component dispersion.

The article (Mospan D.V. et al., 2014) deals with the development of pressure sensors with digital output and built-in self-monitoring of operability and the ability to perform calibration periodically during a device operation in real time, without the use of special reference tools.

As they state in work (D.Yu. Kostin, 2014; Pfeuffer, M. A. R. I. A., 2001), the failures of mass air flow sensors (MAFS) occupy the first place among the failures of the car microprocessor system. Therefore, the problem of new principle development for MAFS operation, as well as the methods for their calibration, remain urgent (Pingel, H., & Heimpold, M., 1983; Powell, J. C. 1992).

2. Calibration Method for Air Mass Flow Sensor

By calibration we mean the process of signal obtaining (analog or digital one) at the output of a calibrated instrument, which, within the required accuracy, would be equal to the reference signals. They use industrial air flow meters as the source of reference signals.

Based on the obtained results in the computer model of the air mass flow converter, it is proposed to use a deformation type of hydrodynamic sensor to measure the mass flow of air. The sensor operation is based on an elastic blade deformation measurement placed in the flow, which arises as a result of flow pressure on the blade surface. By the amount of deformation, the average flow velocity can be determined. The flow rate is defined as the product of the average flow velocity on pipe cross-sectional area and on flow density. Strain gauges are located on the front and the rear (with respect to the flow) sides of the blade. These gauges form the Wheatstone bridge, which measure the blade deformation.

Currently, due to the availability of single-chip microcontrollers (MC) with low power consumption and energy independent memory, the precision analog-to-digital converters (ADC), the leading companies began to switch from analog methods of temperature error correction of semiconductor strain gauge deformation converters (DC) to digital ones. The basis of most digital correction methods is the auxiliary measurement of DC temperature with the subsequent correction of air flow measurement result according to predetermined formulas. In this paper, they discuss a digital correction of the air flow sensor temperature error for the abovementioned device.

In order to determine the DC temperature, one can use the temperature dependence of DC bridge measuring circuit (MS) resistance. In this case, the output signal and the resistance of DC MS will be the functions of the flow rate P and the temperature T:

$$U_{вых} = f_1(P,T), \qquad R_m = f_2(P,T) \tag{1}$$

However, in order to proceed to the calibration of the measuring bridge from temperature, one must take into account the dependence of air density on temperature and atmospheric pressure:

$$\rho(T) = \rho(B_0/T_0)\cdot(T_0/T)\cdot(B/B_0)$$

Here B_0 and T_0 - the atmospheric pressure and the calibration temperature of the sensors. The temperature of the air drawn in from the filter is controlled by a separate thermistor, the temperature of the bridge may differ from the air temperature.

Having measured an output signal and the resistance of DC, and having solved the system of equations (1), you can determine both the required flow rate and the temperature of MS.

In order to determine the functional dependences of the output signal and the resistance of bridge DC MS from the flow and the temperature values, a standard flowmeter of high accuracy was used. In the course of the experiment, the values of the output signal and the resistance of DC MS at measured values of temperature and fixed values of the air flow were measured and tabulated in the reference data at a specially designed stand.

If the reference signals have a temporary instability, it is necessary to average them in time, as well as the calibrated signal. In this case, it is necessary to type the number of measurements that significantly exceed the number of unknown coefficients, and the solution should be carried out by statistical methods. Here and below, the approximation is carried out using the method of least squares.

Let us consider two methods for the statistical solution of equation system (1).

Suppose that the experimental dependence of the output signal U(T) on the flow rate with good accuracy can be described by a polynomial of the second degree:

$$U_{вых}(P,T)=U_0(T)+K(T)\cdot P+\delta(T)\cdot P^2 \tag{2},$$

where: $U_0(T)$ is the initial output signal of TP, K(T) is the sensitivity coefficient of the TP, $\delta(T)$ is the coefficient of TP load characteristic nonlinearity, and T is the temperature of the bridge sensors. These coefficients are TP characteristics. In this case, the equation (2) can be solved directly with respect to the consumption rate P.

Experimentally determined temperature dependences $U_0(T)$, K(T) and $\delta(T)$ are nonlinear ones and are approximated by the following expressions:

$$U0(T)=a_0+a_1\cdot T+a_2\cdot T^2 \tag{3}$$
$$K(T)=b_0+b_1\cdot T+b_2\cdot T^2 \tag{4}$$
$$\delta(T)=c_0+c_1\cdot T+c_2\cdot T^2 \tag{5}$$

Thus, with an independent measurement of temperature, the functional dependence of the output signal of the bridge DC MS on the flow rate and the temperature has the following form:

$$U_{вых}(P,T)=(a_0+a_1\cdot T+a_2\cdot T^2)+(b_0+b_1\cdot T+b_2\cdot T^2)\cdot P+(c_0+c_1\cdot T+c_2\cdot T^2)\cdot P^2 \tag{6}$$

The temperature dependence of DC resistance on temperature is non-linear one and can be represented by the following expression:

$$R_m(T)=d_0+d_1\cdot T+d_2\cdot T^2 \tag{7}$$

The dependence of the bridge DC MS resistance on the flow rate is negligible: when the flow rate changes from zero to maximum, the resistance change is less than 10^{-3} R_m over the entire temperature range.

Knowing the magnitude of the output signal and the resistance of DC MS, and solving the system of equations (6) and (7) with respect to the sought P and T, we can determine both the flow rate and the temperature of TP. In this case, when the equality of the TP temperature and the measured medium is ensured, it is possible to obtain a sensor that simultaneously measures both flow and temperature. An additional thermistor will allow for control and autocalibration.

In the case where only the flow rate is the sensor output signal, the TP temperature value can be determined from (7) through the bridge resistance value $T=f_3(R_m)$, so that the functional relationship of the output signal with the flow rate will be described by the following expression:

$$U_{вых}(P)=(a_0'+a_1'\cdot R_m+a_2\cdot R_m{}^2)+(b_0'+b_1'\cdot R_m+b_2'\cdot R^2{}_m)\cdot P+(c_0'+c_1'\cdot R_m+c_2'\cdot R^2{}_m)\cdot P^2 \tag{8}$$

Solving the equation (8) in a direct algebraic way with respect to the quantity P, we obtain the following:

$$P=\frac{-\left(b_0'+b_1'\cdot R_m+b_2'R_m^2\right)+\sqrt{D}}{2\cdot\left(c_0'+c_1'\cdot R_m+c_2'R_m^2\right)}$$

$$D=\left(b_0'+b_1'\cdot R_m+b_2'R_m^2\right)^2-4\cdot\left(a_0'+a_1'\cdot R_m+a_2'R_m^2-U_{вых}\right)\cdot\left(c_0'+c_1'\cdot R_m+c_2'R_m^2\right) \tag{9}$$

where: $a_0'..a_2'$, $b_0'..b_2'$, $c_0'..c_2'$ — the coefficients that are found during a sensor calibration.

The method of least squares allows to solve an inverse problem if it is possible to select the function of airflow dependence on the output signal of the bridge at a known sensor temperature. Instead of the output signal, you can use a square root or a logarithm of this value to cover a large range of the measured flow rate. In our case, square root will be the most suitable one for the deformation sensor:

$$P\left(T(R),U_{вых}\right)=A\left(T(R)\right)+B\left(T(R)\right)\cdot\sqrt{U_{вых}}+C\left(T(R)\right)\cdot\sqrt[4]{U_{вых}} \tag{10}$$

Here $U_{вых}$ — calibrated bridge indicators;
R — bridge resistance.

Expanding the required flow rate depending on the polynomial of the square root or the logarithm of an output signal, we find the coefficients of the polynomial, which will be the functions of temperature. This temperature dependence is either tabulated or approximated by a polynomial whose parameters are stored in the processor memory.

When you calibrate the microprocessor sensor, the values of the output signal and DC MS resistance in (9) or (10) are replaced by the corresponding N codes of the analog-to-digital converter (ADC). In this case, when you find the coefficients, in addition to TP error, the ADC error is taken into account additionally, which in its turn improves the sensor accuracy additionally.

Figure 1 shows the block diagram of a sensor with a digital output, in which the described method is implemented to determine the value of the temperature-corrected flow value.

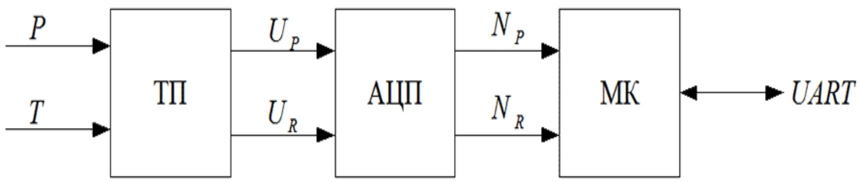

Fig 1. Block diagram of pressure sensor with digital output

The flow rate P is converted to the voltage U_P, taken from the diagonal of the bridge DC MS. This voltage is applied to one of ADC inputs to convert it to a code. In order to determine the resistance of DC MS a resistor is plugged in the power diagonal circuit, the resistor voltage drop U_R is fed to the second input of the ADC. N_P and N_R codes, corresponding to the U_P and U_R voltages are periodically read by a single chip microcontroller (MC). The latter, using the expression (9), calculates the required air consumption value corrected by temperature.

The received value of the flow can be read by the digital interface at any time. However, in the future, a signal is sent to the motor control system in the form of voltage or frequency. Therefore, the calibration result is the inverse dependence of the base signal on the calibrated signal. This relationship is remembered either by a matrix or by a polynomial, as in expression (6) or (10).

As it was said before, the coefficients of equation (9) are determined during the individual calibration of the sensor and are stored in the energy dependent memory of MC data. The calibration procedure is the following one:

- Using the least-squares software, the coefficients of the polynomials used to correct the temperature error are calculated;
- Then these coefficients are put down to the energy independent memory of MC data via the digital interface.

The described technique allows to correct both basic and additional (temperature) errors of the additive, multiplicative and nonlinear character of all functional units of the sensor, and first of all - the strain-resistive converter.

3. Summary

The article describes the method of temperature change consideration during a mass air flow sensor calibration. The basis of the sensor is a blade made of an elastic material with applied strain gauges, the deformation of which is measured and recalculated into a mass flow of air. They proposed the system of nonlinear equations that allows one to determine the mass flow and air temperature based on known values of signal at the measuring bridge output and the measuring circuit resistance. It was shown that it is expedient to use the square root of the output voltage in the function of the air flow dependence on the output signal of the measuring bridge, which allows to cover a large range of flow variation. The coefficients of the polynomial, which act as the temperature functions, are selected during the calibration using the least squares method and then are recorded into the memory of the sensor microcontroller.

Conflict of Interest

The authors confirm that the presented data do not contain a conflict of interest.

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References

[1] Vilop L.E. (2012). Autocalibration of the measuring channel at the channel input for electrical value conversion. // Bulletin of the Samara State Aerospace University, 7 (38), 54 - 58.
[2] Gritsenko A.V., Larin O.N., Glemba K.V. (2015). Diagnostics of air mass flow sensors for passenger cars. // Bulletin of UrSU. Series "Mechanical Engineering", Volume 13, No. 2, 2013. Measurement. Monitoring. Management. Control, 1(11), 17 - 22.
[3] Mospan D.V., Rozhnova T.G., Allahveranov R.Yu., Goncharov S.A. (2014). Pressure sensor with automatic self-monitoring of operability and self-calibration. // The technologies of instrument making, 2, 23 - 25.
[4] D.Yu. Kostin. (2017). The method of air mass flow sensor diagnosing on a car and the device for its implementation. // Technical sciences for agroindustrial complex of Russia. The materials of the international scientific-practical conference. Chelyabinsk, 170.
[5] Kokoszyński, D., Korytkowska, H., Adamski, M., & Bernacki, Z. (2002). Evaluation of slaughter traits and proportion of fatty acids in breast muscles of strain A55 and P77 ducks. Rocz Nauk Zoot suppl, 16, 317-21.
[6] Książkiewicz, J. M. (2003). Comparison of reproduction and carcass traits in light type of ducks of four conservative flocks over eight generations. Archives Animal Breeding, 46(4), 377-389.
[7] Mazanowski, A., Ksiazkiewicz, J., & Kisiel, T. (2001). Evaluation of meat traits in four-strain crossbred ducks. Roczniki Naukowe Zootechniki, 28(1), 25-43.
[8] Pfeuffer, M. A. R. I. A. (2001). Physiologie effects of individual fatty acids in animal and human body, with particular attention to coronary heart disease risk modulation. Archives Animal Breeding, 44(1), 89-98.
[9] Pingel, H., & Heimpold, M. (1983). Efficiency of selection for live weight and breast meat proportion in ducks. Archiv fuer Tierzucht (German DR).
[10] Powell, J. C. (1992). The domestic duck–a preliminary investigation of eating quality. In Proceedings of the 19th World's Poultry Congress. Amsterdam, The Netherlands, 106-108.